Report as of FY2008 for 2008CA248B: "Simulating and understanding variability in runoff from the Sierra Nevada"

Publications

- Articles in Refereed Scientific Journals:
    - Kapnick, S. and A. Hall, 2009: Observed climate-snowpack relationships in California and their implications for the future. Conditionally accepted to Journal of Climate
- Other Publications:
    - Kapnick, S. and A. Hall, 2009: Observed changes in the Sierra Nevada snowpack: potential causes and concerns. California Environmental Protection Agency and California Energy Commission Draft Report CEC-500-2008-XXX, in press

Report Follows

This study aims to understand the origins of recent and future changes in snowpack and runoff in the Sierra Nevada using both observational and modeling techniques. Together, observations and models indicate the snowpack will likely undergo dramatic changes in the coming decades, and moreover that those changes are already detectable and well underway.

To study the snowpack from an observational perspective, we examined snow station observations and surface temperature data. Monthly snow water equivalent measurements were combined from two data sets to provide sufficient data for statistical analysis of snowpack evolution during the snow season from 1930 to 2008. The monthly data is used to calculate peak snow mass timing to assess variability in timing and magnitude of snow accumulation and melt from February 1st to May 1st. Since 1930, there has been a trend towards earlier snow mass peak timing by 0.6 days per decade. Since 1948, regional averaged March and April temperatures have also increased at a rate of 0.1ºC per decade. Statistical analysis shows that the trend in snow mass peak timing can be explained by its sensitivity to local March and April temperatures (see accompanying figure, which shows how closely linked averaged March and April temperatures are to the peak of the Sierra snowpack). The snow mass peak timing is shown to shift earlier in the season by 3 days per 1ºC increase in averaged March and April temperatures. Given scenarios of warming in California, we can expect to see acceleration in this trend; this will reduce the warm season storage capacity of the California snowpack.

This observational study paints a picture of a rapidly changing snowpack already responding to global climate change. These results are consistent with the modeling component of our study. To model the changing snowpack, we carried out a climate simulation with a 36-km regional atmospheric model covering all of California. In this simulation, the model is forced at its lateral boundaries with output from a global model simulating future climate change. This allows us to examine the effect of increasing greenhouse gases on the Sierra snowpack. By the mid-21st century, we project significant decreases in snow water equivalent averaged over the wet season in the Sierra Nevada. The projected snow decrease is especially large in the lower-elevation northern Sierras. Here it is about 30-40% in fall and almost 60-80% in winter. The decrease in snow is due to a significant decrease in snowfall and is likely augmented by increased likelihood of melting due to warming. Though the likelihood of snow melting is greater in the warmer climate, reducing snowpack, the amount of snowmelt itself decreases throughout the cold season in response to the reduced snowfall. Again, the largest reduction occurs in the northern Sierra Nevada where the snowmelt decreases by 38% and 54% for fall and winter, respectively.

A theme emerges from our observational study showing recent earlier snowmelt in response to warmer temperatures and our modeling study showing reduced snowpack in future decades due to warmer temperatures. Together, they indicate the snowpack will likely undergo dramatic changes in the coming decades, and moreover that those changes are already detectable and well underway. These results are directly relevant for California's reservoir infrastructure, whose capacity was designed assuming continuation of the natural hydrologic reservoir of the Sierra snowpack. Clearly this is not the case.

To complement observational studies of Sierra Nevada snowpack, we have constructed high-resolution simulations of California climate and hydrology using the Weather Research and Forecasting (WRF) regional climate model. We compare model output on a 3 km grid over the central Sierra with daily snowpack observations at 41 sites during the 2001-2002 water year. Preliminary results suggest that WRF accurately reconstructs snowpack development through March 1, 2002 at 18 of the stations, with substantial underestimates of snowpack at the others. Likely sources of error include primitive energy balance calculations in the 1-layer snowpack model currently coupled to WRF and inaccuracies in the partitioning of precipitation into rain and snow.